Walking Moai?

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Uniqueness of Rapa Nui Megaliths?

Stones up to 1.5 tons are usually slung on poles for transport. Thirty ton Assyrian winged bulls on sledges rest on short ambiguous objects, some parallel and some perpendicular to the line of motion, which may be wooden rollers or gliders. Sixty ton Egyptian pharaohs are dragged on sledges over wooden planks without rollers, upright and with lubrication, as shown in Figure 1. One-hundred ton Egyptian columns on barges are shown lashed to sledges. So suggests Heizer (1966) in his survey of ancient heavy transport. He also notes the propensity of heavy loads to crush wooden rollers and states categorically, "...the use of wooden rollers cannot be demonstrated for any stone-moving culture in the New World, and at best the evidence is weak for pre-Roman Old World societies".

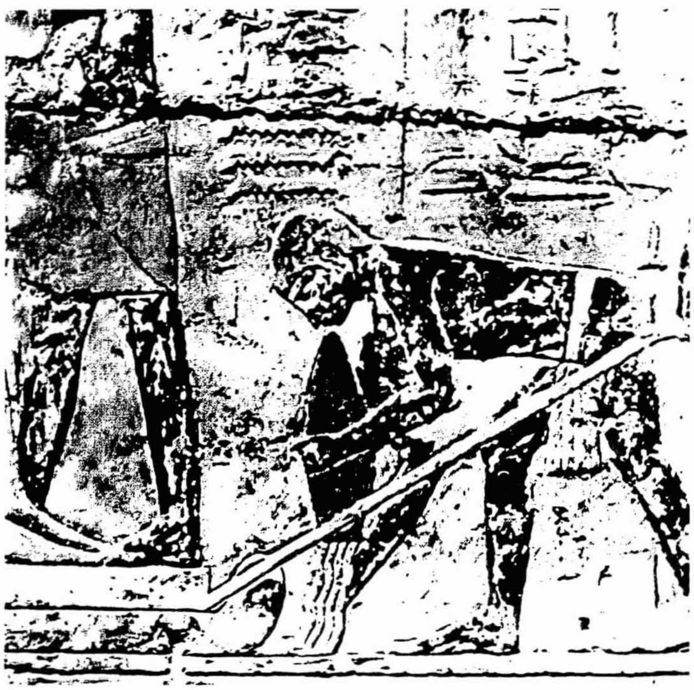

Figure 1. Transporting the statue of Ti (2400 BC). Water, milk, and oil have been suggested for the lubricant being poured in front of the sledge. (There is something strange about the proportions of the pourer's apparent right arm.) Ti's feet are shown at the left of the picture, suggesting that he was about 4 meters tall (if somewhat more slender than the average *moai*). From Steindorff (1913).

Thorpe and Williams (1991:67) note that, contrary to popular opinion, there is "...no evidence for human megalithic transport exceeding ca. 5 km" over land in Northern Europe, and only eight stones that were moved more than 2 km. Even the fabled sarsen stones of Stonehenge are now recognized as glacial erratics left nearby on the Salisbury plain.

Pyramids aside, it seems possible that the Rapanui moved more fragile carved monoliths farther over land, with fewer human resources, than any other megalithic society, and they might have developed transport techniques which are not found elsewhere. It may not be necessary to constrain our hypotheses about *moai* transport to methods known from other cultures: perhaps we should not immediately dismiss rollers or other unique approaches.

Transport Modes

The major methods suggested for transporting *moai* are sketched in Fig. 2 and collected in Table 1. Bahn and Flenley (1992:134) mention additional entertaining but unlikely approaches. Some comments are in order.

I. Dragging a sledge made of an Y-shaped tree. Much energy is dissipated in friction. "This is not the way it was done", say the islanders (Heyerdahl 1989:208).

Ia. There is an oral tradition suggesting dragging with lubrication by sweet potatoes. Taro, *totora* reeds, palm fronds, and seaweed might also be candidates, but the quantity required is a major difficulty. A 10 km lubricated path, 2 m wide and 1 mm thick, would require 20 m^3 (roughly 20 tons) of lubricant, which seems an implausible drain on island resources, whatever the lubricant.

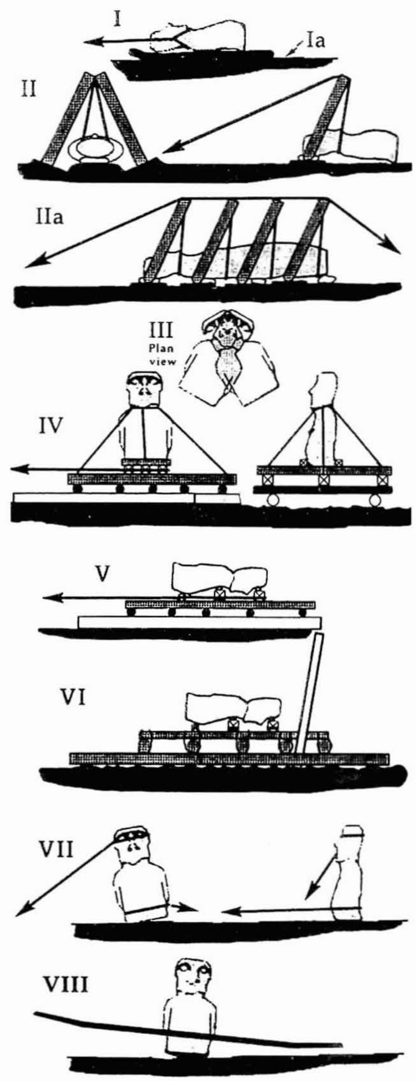

Figure 2. Cartoon of transport modes. Structural beams are shown in gray and square to differentiate them from black circular rollers (although they would have been round in practice). See text for details.

Table 1. Suggested methods of transporting *moai.*

Method	Authority	Manpower	Speed
I Dragging on Y-shaped sled	Heyerdahl (ca. 1950)	180	—
II A-frame step-swinging	Mulloy (1970)	90	—
III Horizontal pivoting	Adam (1988)	—	—
IV Upright rolling	Love (1990)	25	20 m/min
V Horizontal rolling	Van Tilburg (1994,1998)	60	failed
VI Levered sliding	V. R. Lee (1998)	25	30 m/day
VII Walking, with ropes	Pavel (1990)	15	100 m/day
VIII Walking, on rocking foot	MacIntyre (here)	8	150 m/hr

Perhaps only the difficult stretches were lubricated.

II. A swinging A-frame applies beneficial leverage and cuts friction losses dramatically. The legs must probably stand on (movable) rock bases, and either the bases are angled or the legs tied at the bottom.

IIa. Two or more A frames remove all serious friction losses; lifting can be minimized with tall legs; with a rope at the back the load can be lowered gently — and the approach might described as "walking". With functional pulleys (even lubricated non-rotating blocks) at each bipod, one might replace the individual slings with a continuous supporting rope which would automatically equalize the load at each bipod. This has apparently not been tried.

III. Horizontal pivoting. This works better for long self-supporting objects such as canoes. Most *moai* are a bit blocky, and long ones would probably have to be supported on a platform of logs. There is a serious trade-off in positioning the pivot point between available forward motion per swing and the ability to support and balance the load. Support is probably not feasible without building a rigid truss, and I suspect that the method, if ever tried, would rapidly evolve into method VII below.

IV. Upright rolling seems to combine the disadvantages of instability and the need for a complex platform with the problems of rolling over rocky or deformable terrain, but it works well for short distances on hard level ground. The statue itself is minimally stressed in this mode. Here and in the next mode, we have overlooked the ropes that bind the platforms. These should not interfere with the rollers, and so cannot wrap around the logs in contact with the rollers. Presumably they would have gone around side branches or short cross members inserted for the purpose.

V. Supine (or prone) rolling is stable and often recommends itself (most recently, to Grau 1998). However, it is not free of the roadbed problems described by Heizer and so requires a log track. *Jubaea* (*Paschalococcos*) has been proposed for rollers (Grau 1998), but my experience with date palm (*Phoenix dactylifera*) trunks is that the hard rind cracks easily and the softer fibrous interior deforms; I would not recommend them for heavy service. Bahn & Flenley (1992:135) suggested 50 cm *toromiro* rollers. However, the idea of rolling has been pretty well scuttled since (in the best scientific tradition) Van Tilburg falsified her own rolling hypothesis (Van Tilburg 1994:155 ff) in a field experiment. She used a low-density model and found such severe alignment problems with rollers that she immediately changed to a sliding sled (Van Tilburg 1996, Lee 1998).

A supine position (rolling or sliding) leads to problems when it comes time erect the *moai* at the *ahu*: one wants to approach the *ahu* with the *moai* "feet" first and prone, so that it can be tilted into position without rotation.

VI. Levered sliding. A sled, like that proposed for rolling, is instead slid on lubricated logs. The driving force is applied by levers rather than ropes (Lee 1999). The same approach might work with a vertical *moai*, but the method would certainly contribute to deforestation.

VII. Walking by tilting and swiveling an upright statue with ropes requires precise coordination of 2 groups (4 groups to take advantage of the rhythm of pendulum rocking). This, or something similar, seems the first suggestion of anyone who has himself moved objects like refrigerators single-handedly, but it has been tried and quickly spalls the bottom corners of the moai. Pavel (1990) incorporated a rounded base (like the rocking foot described below) on his cement model. The line between necessary metastability and disaster is uncomfortably thin unless the base is correctly designed, and mock-ups moved in this manner fall over rather too frequently.

VIII. A rocking foot and timber rig seems a fairly sophisticated solution, but may offer the fastest and easiest transport.

Oral Tradition is Sometimes Valid

We know that legends can be corrupted without the teller being aware of anything amiss. (Consider how easily the Mesopotamian flood moved into the Bible and then into "traditional" native folklore around the world after the arrival of missionaries.) We also know that native informants can and do show *Clever Hans* behavior, observing the recipient and supplying the information that generates the best response. The latter behavior is common in subjects hypnotized in attempts to recover details of partially forgotten incidents.

On the other hand, Australian aboriginal legends accurately describe the climate and biota of the Ice Age, characteristic of Australia when the Aborigines first arrived.

One can reconstruct eyewitness accounts of specific volcanic eruptions from *Hesiod's Theogony*, written after 800 years of oral transmission (Brown 1953). An Indian archaeologist told of being puzzled by rectangular deposits of ash in wooded country. It had been suggested that these were ash dumps from earlier glass kilns, but there was no supporting evidence for kilns. Finally he asked a village child, and got an immediate answer: "Cattle pen. They burned the manure." Historical evidence showed that cattle hadn't been grazed there for 3000 years, but subsequent investigation supported the child's story. Although children's lore is continually subject to topical additions, the Opies (1959) document the survival of numerous examples for periods of centuries, many from mediaeval times, some from the time of Nero, and a few from Classical Greece. Some examples are known in English, French, German, Norwegian, Spanish, Rumanian, Arabic, American, and Chinese; and other unlikely combinations. Such traditions survive because they are annually transmitted from a 7-year-old to a 6-year-old, are apparently forgotten by puberty, and never enter adult consciousness to interact with other ideas or be checked against contemporary appearances.

Thompson (1972) offers two examples of "folk memory". Near his hometown of Hadstock, local tradition held that there had once been a monastery on the north side of the village. "Documentary evidence recently brought to light suggests that there was such a monastery, sacked by the Danes about AD 1000". Near Chichén Itzá in Yucatan, an underground shrine of

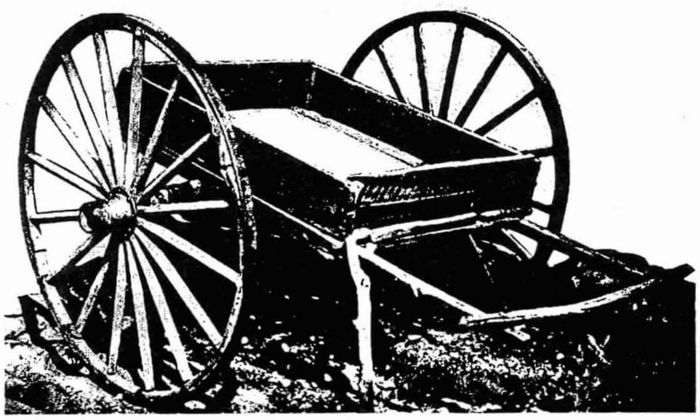

Figure 3. Mormon hand cart of the 1850s, used on the 1300-mile Mormon Trail from Omaha to Salt Lake City. The wheel diameter is 5 feet (1.5 m), with a steel or rawhide tire, and the carts normally carried about 250 kg. The trip took 4 months with oxen and a covered wagon, but 3 weeks less with a handcart (Photo courtesy of the Mormon Museum of Church History and Art).

the Tlalocs was sealed off ca. AD 900, and only recently rediscovered. But the local Maya knew all about it.

Thoreau mentioned an old Indian myth to the effect that Walden Pond (no inlet, no outlet) had been a hill before it collapsed into an unusually deep "bottomless" pond. This is correct; it is a kettle pond, formed when a remnant of the glacier finally melted out from under the insulating cover. Thoreau, writing before this process was understood, thought it a very odd story. The oral tradition apparently survived 5000 years or more since the melting of the last bit of glacier.

The point is that one should not automatically dismiss traditional oral information. If legends say *moai* "walked" to their *ahu*, there is a good chance that they did just that. Certainly the islander's unlikely story that Rapa Nui had once been heavily forested has been verified. There is always the chance that the "problem" with walking *moai* lies in our own failure of imagination.

How to Move a Refrigerator

If one has a background of machine design and construction, coupled with experience in moving lethally heavy and awkward objects over uneven terrain without machinery, there is an obvious first approach to transporting a *moai*. To move a large refrigerator over a smooth surface in the absence of a wheeled dolly, one does not immediately consider laying it horizontally on small rollers. One tips it back on its corners and pivots it around one and then the other, quite literally walking it. To move a refrigerator over a rough or yielding surface in the presence of a wheeled dolly, one tips it back and walks it, as small wheels will only make the task more difficult. Whether a Rapanui artisan without experience in moving refrigerators would find this approach equally obvious when asked to move a small *moai* is not clear, but the method might have left field marks that are worth looking for. There is some historical support for moving lesser loads with large wheels. The Mormon Handcart Expedition of 1856 had wheels 5 feet in diameter: Figure 3 shows a handcart replicated for the 150th anniversary re-enactment of the Mormon Trail migration. April mud in the Plains and September snow in the Rockies limited wheeled travel to a 4-month period; to make 3300 km to California (the Mormon's original destination) required an average of 27 km/day (including crossing 2 major mountain ranges), so transport efficiency was paramount. However, the handcarts carried only 250 kg.

Epic movies show 2.5 ton stones (1/5 the weight of the average *moai*) for the Egyptian pyramids being pulled on log rollers by massed phalanxes of slaves. Later interpretations (Parry 1997) suggest that certain curious objects, found by Flinders Petrie (1909) in New Kingdom temple-foundation deposits, are late models of the "contrivances made up of short pieces of timber" mentioned by Herodotus as the means to transport the pyramid stones. They are most logically interpreted as quarter-circle segmented wheels (rolling cradles). A square stone forms the axle of a pair of wheels each made from four such segments, in the manner of Figure 4. The hauling rope

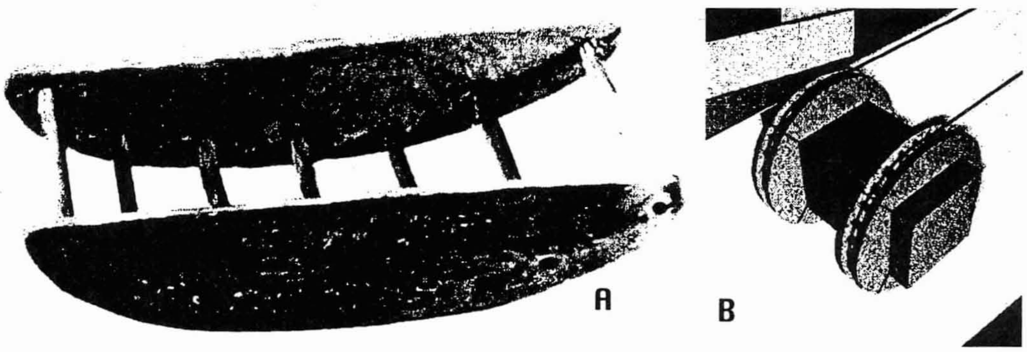

Figure 4. A: Model of rolling cradle (segmented wheel) for moving stones for the Egyptian pyramids. (Courtesy of the Metropolitan Museum of Art, Gift of Egypt Exploration Fund, 1896, #96.4.9). B: Model of 8 rolling cradles assembled into wheels with 2.5 ton square stone as axle. This is a computer reconstruction of a very grainy and pixilated photo taken with permission from Parry (1997).

is wrapped around the (recessed) outer diameter. Parry describes tests at the Obayashi Corporation near Tokyo in which a 2.5 ton concrete "stone" was pulled 15 m up a 1:4 ramp (14°) by 16 men in 1 minute.

Unfortunately, there is no evidence for such segmented wheels on Rapa Nui, nor do they lend themselves well to moving irregular objects which must be carefully erected at the end of the journey.

Route Modeling

The net work of transport is mgDh: force mg (mass times gravity) times the height Dh the mass is raised. This is trivial to compute from a topographic map, but useful only in comparing segments of different routes. Remember that a round trip from quarry to *ahu* and back—by any pair of routes whatsoever—does no net work, because Dh for a closed loop is zero.

It is a brave modeler who would venture to estimate the gross work of transport, including nonproductive accelerations, roadbed deformation, transient changes in height of the center of gravity from irregularities in the roadbed, (and from noncircular and bent rollers if rollers were contemplated), slippage of feet, rope stretching, components of human effort which are not along the vector direction of motion, pry-bar bending, fulcrum sliding, support-structure distortion (flexing, dilation), expenditure of muscular energy with no net motion (as in pulling on a non-moving object or taking some of the weight off of a roller or sled), and other real-world inefficiencies. Recall that both the best possible worm gear, and human muscles themselves, are less than 50% efficient. The question is not whether transport is 10% or 20% efficient, but how many 9s describe the inefficiency: 90%, 99%, 99.9...%? The differences seem small—but every additional 9 multiplies the gross work by a factor of 10, and renders suspect sociological conclusions drawn from labor "requirements" unless the gross work is estimated from field experiments.

The most efficient route on a digitized map may contain a succession of 5 cm obstacles on the ground; the smoothest route on the ground might be across the most yielding substrate. In either case, a simulation—however interesting to program—has little relevance to the real world. And as Hunter-Anderson (1998) points out, group projects in small societies are a form of social bonding (like early American barn raising and sewing bees), and are not governed by considerations of efficiency. The more the merrier.

Finding the Center of Gravity

Chief among the problems of moving a vertical *moai* is stability, and the first step in examining stability is to locate the center of gravity. For this one needs mass as a function of height. In the absence of detailed volumetric data, one can attempt to glean something from photographs of *moai*. It seemed as though Van Tilburg (1994) had provided much of what was needed, in the form of "Sam", the "Statistically Average Moai" drawn by Arévalo P. in her Figure 9, who bears some undefined relation to the polystyrene and laser-scanned model of *moai* 01/53 of Ahu Akivi—"a particularly good example of the statistically designated average statue"—whose digital avatar Van Tilburg rolled over a virtual roadway. Both are 4.05 m tall and weigh 12.5 tons, but the resemblance stops there.

I digitized the drawing of Sam and from the front and side views computed a value for the mass distribution by the trapezoidal integration. The calculated volume is 4.66 m^3, the center of gravity 158 cm above the base, and the density 2.68 T/m^3. But Van Tilburg (1994) gives a volume of 5.96 m^3, a c. g. at 136 cm, and the literature value of density of tuff is ca. 1.82 $tons/m^3$ (Bahn & Flenley 1992:134)—while Van Tilburg's (unreported) density comes out to be 2.10 $tons/m^3$. There are obvious inconsistencies here. Bahn's (1995) rather ungenerous review of Van Tilburg's book pointed out a number of minor errors; I wondered if perhaps I had found another. When I asked Van Tilburg about this discrepancy, she stuck by her numbers and objected strenuously to my use of Sam in this manner, claiming that this was an "inappropriate" use of the drawing. Still, I find that this is not the only instance of difficulty in calculating *moai* density: the UCLA field experiment intended to use a cement model weighing 15 tons, but it was closer to 9 tons when cast.

I then suggested a joint paper with Van Tilburg in which we compared transport methods using the same digital *moai* moving over the same digital road: she did not respond, so I did what I could. Re-scaling the drawing of Sam to agree with Van Tilburg's measured width gave a volume as 6.82 m^3 and a density 1.83 tons/m, as it should, so I adopt this compromise. Rescaling does not move the center of gravity vertically, so I use Tilburg's value, on the grounds that the discrepancy arises from my assumption of constant cross section.

The front and back views of the original Sam differ by 11%, within acceptable limits for "eyeball" artistic drawings since it is not immediately noticeable to the naked eye in the original drawing. Still, I think that the average scientist, faced with a drawing described as a "statistical average" of 134 *moai* in a scientific work, is entitled to interpret it as accurate to 1 part in 134 (0.75%), and useful as it stands to anyone interested in the statistics of the average *moai*. A more informative caption for Van Tilburg's Figure 9 might have been "an artist's impression (not to scale)".

Perhaps more to the point, Heyerdahl (1989:226) notes that the statues are designed so that the center of gravity is low, near the navel, so that they can safely be tilted nearly 30°.

A Design Modification

We know from Pavel's experiment (1990) that walking a *moai* with a flat bottom spalls the corners. The response of the scientific community to this discovery seems to have been indignation at the damage: "...a cry of protest in the community and among scholars", as Van Tilburg put it (1994:154). I suggest that a more appropriate response is to recognize the value (and inevitable cost) of negative evidence (e.g.: the UCLA experiment itself!) even though our culture (and journals) are reluctant to admit that the majority of scientific experiments can be expected to fail. Then one can think about how to prevent this sort of damage.

Perhaps the easiest way to obtain non-destructive walking is with the curved "rocking foot" of Figure 5. If one can believe drawings and photographs, many of the *moai* at reconstructed *ahu* (e.g., Sam, Ahu Naunau, Ahu Huri a Urenga, Ahu Akahanga) are standing on a sloping support, indicating that the base of the *moai* was reshaped to match the site at erection time. Heyerdahl (1989:224,236) notes that the basal curvature of *moai* in transport increases with distance from the quarry, as though a rocking foot developed from abrasion. We know from the independent evidence of shards at the *ahu* that *moai* were sometimes retouched after transport, and Heyerdahl mentions one whose base was so worn that it had to have a new set of hands carved on it. Retouching would repair any damage to the corners of the base and remove the more severely worn rocking feet.

The rocking foot has the advantage of making erection at the *ahu* almost trivial. (The UCLA experiment required a full day of jockeying and struggling to accomplish this task.) If the rocking foot is integral, the erect *moai* is moved into position and leaned back for trimming (logs and levers here). If the foot is a separate wooden piece, as in Figure 8, the *moai* bottom does not need shaping to fit the *ahu*. The simplest method would be to approach a stone the same height as the foot, loosen the foot, and continue to walk the *moai* a few feet onto the stone pedestal with minimal rocking. The rocking foot and timber rig is an optimal tool for fine positioning. If adjacent *moai* were in the way, the side beams could be removed for final positioning.

STABILITY

One does not want a walking *moai* to fall over. This is my principal worry about Mode VII: if a *moai* starts to topple, one cannot push on a rope, and one cannot correct the motion by pulling from the opposite side once past the angle of metastability. (Indeed, Love's concrete model fell over twice before it was mounted on a sledge). Figure 5 investigates the lateral stability of the simplest case, a circular rocking foot. At its most efficient, rocking motion would take advantage of the natural period of the upright *moai*. To produce a natural period, one shapes the rocking foot so that (like a pendulum) the center of gravity is highest when motion reverses. The easiest way to do this is by raising the center of the rocking circle above the center of gravity. *Ceteris paribus*, the

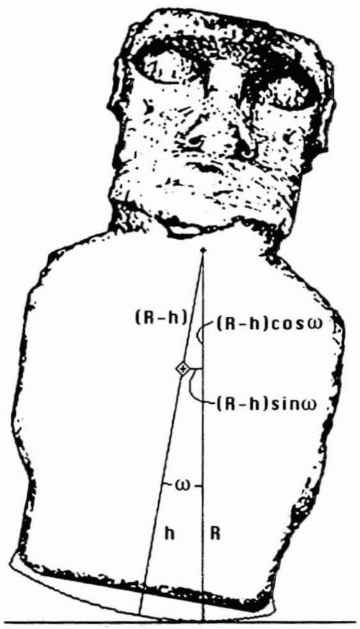

Figure 5. A rocking foot on Sam, tilted 10°. The rocking radius is arbitrarily shown as 250 cm. We ignore the small change in the location of the center of gravity by the addition of the rocking foot (After drawing by C. Arévalo, in Van Tilburg 1994, Figure 9)

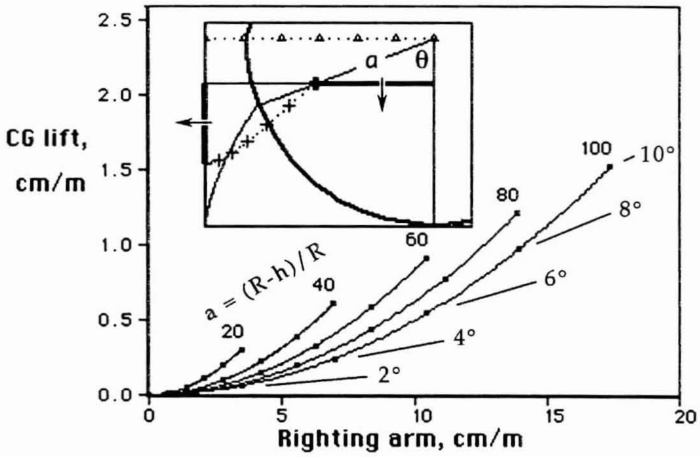

Figure 6. Dynamics of a circular rocking base. Inset: Circular base tilted (exaggerated for illustration) showing that the locus of the center of gravity (the heavy cross) is a cycloid. The heavy line segments are the 2 coordinates that are plotted. Main graph: Righting arm and c. g. lift, normalized to a 1m radius, with curves for a range of a, the fractional radial distance from center of circle to c.g., and varying tilt angles. This is illustrative only, since any desired relationship can be obtained by reshaping the foot.

larger the tilt, the larger the forward stride 2Rθsinω, where θ is the tilt angle and ω the forward rotation angle. An even safer approach is to increase the radius of curvature of the foot at the ends, which can make it virtually impossible to tip over, as shown in Figure 6. Rotational abrasion of the pivot points during walking produces this flattening effect automatically. Thus, while evolute curves were first studied by Apollonius of Perga 600 years before Rapa Nui was settled, one need not understand them analytically to achieve such stability (Figure 7).

Experiments with models suggest that a blocky object with Sam's aspect ratio can easily be moved forward its own diameter in 16 oscillations. For Sam, this mode comes to something like 6.25 cm per pace (one left step, one right step). The oscillation period $T = 2\pi\sqrt{(l/g)} = 2\sqrt{l}$ is a minimum of 2.5 seconds, or 24 paces/minute, which is some 90m/hr. Walking a *moai* 16 km is thus something like a month-long project, which is only 10% of the carving time. With better coordination, longer steps can be taken.

A WALKING RIG

The walking rig photographed in Figure 8 requires 12 tree trunks, 2 of them perhaps 10 m long. None need be straight. Incidental fittings include short cross-bracing, many short pieces of rope for lashing the timbers together, and perhaps some wooden wedges for obtaining a tighter fit than is possible with rope alone. The timbers are reusable and formed a structure which could have been pegged together for added rigidity; the many short ropes probably wear out. Transport is incremental in small steps, interruptible at any time, and can cope gracefully with small gradients. It would be described as "walking" by anyone who participated in it.

Motion up a gradient requires energy input, applied if necessary by climbing onto the lever. Rotating the *moai* involves friction against the ground and probably consumes the most energy, but again, the effort can be applied at the end of a long lever. The long lever limits rotation both in tilt and in forward step and, in practice, these will be determined by the rhythm of the work.

Like all good engineering designs, the rig shown in Figure 8 evolved as it was built, becoming simpler and more functional with each revision. The universal aim of good design is to achieve the desired goal with the fewest components, least material, and simplest structure. Presumably the same criteria and the same evolutionary improvement of design would have occurred automatically on Rapa Nui, had anyone built such a rig. The final design, with many *moai* moved, would have been an improvement over the model in the photograph, but it would not have survived long after deforestation made logs unavailable.

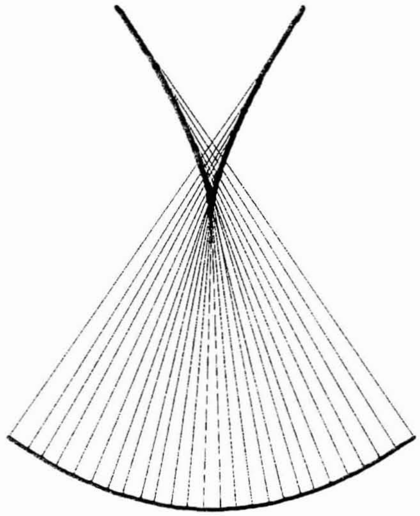

Figure 7. Example of rocking base that is stable against tipping. The fan of lines represent instantaneous radii of curvature, ending at the curved V at the top, which is the evolute of the non-circular base (the locus of its center of curvature). If the center of gravity lies below the tip of the V, it becomes harder and harder to tip sideways. This approximates the shape which will be produced by normal wear during walking. The curvature is exaggerated to keep the evolute on the page.

As one example of design evolution, in an early try, the upper ends of the 4 props were loosely linked by a single rope around the head to hold them more-or-less in place while the lower ends were fixed at the appropriate angles. This fails because fore-and-aft (pitch) trimming and left-and-right (roll) trimming are logically separate operations. The improved design uses 2 linking ropes around the head, at somewhat different levels. Some of the asymmetric ropes are late additions to correct slippage, etc.

The model is not optimized with respect to dynamic features such as the height of the tree trunks with respect to the people pushing on them. (The front arm is still too far off the ground, and will be lowered again after lunch.) It is probably important to locate the vertical center of effective effort (after correction for ground friction) as close as possible to the center of resistance (somewhere between the center of gravity and the ground) to minimize fore-and-aft instability), but the correct location can only be determined by experiment. The relation between the center of gravity and the center of rotation would also quickly be optimized, not by analysis, but by experiment. It takes no work (other than that of substrate deformation) to rock an object when these radii are equal; on the other hand, there is then no righting moment and no rhythmic oscillation. This may sound abstract and analytical when phrased in the language of engineering, but would be optimized empirically in use. If the roadway were sloping, one could maximize stability by adjusting the fore-and-aft angle of the base to match. This need be no more complicated than driving a couple of temporary wedges between the base of the *moai* and a (detachable) rocking foot. The timber rig hits the ground and stops both pitch and roll while the moai is still safely inside the stability limits.

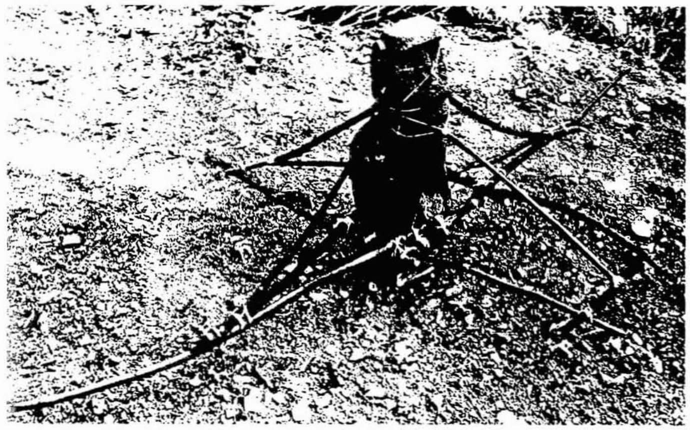

Figure 8. Photograph of a model walking *moai* with a wooden rocking foot. This moves with refreshing velocity across relatively very rough terrain. Note the difference between the flattened track behind the *moai*, and the uncompressed rubble in front. Note also that few of the timbers would make good rollers, or even good "ladders" for sliding transport in the matter of Lee (1999).

In common with other methods of "walking" a *moai*, this one prefers a firm and relatively even substrate (which may still be much rougher in detail than the surface needed for rolling). The pressure of Sam at a mass of 12.5 tons (metric) when tilted onto an 0.3 m^2 footprint is 409 kilopascals or 60 psi. My feeling is that any terrain that can be negotiated (however awkwardly) on a bicycle with high-pressure tires can be traversed by a walking *moai*.

Manpower usage in the walking mode is quite different from the rolling or sliding modes. Rolling transport, according to Van Tilburg's graph (1994:157), would have been labor intensive for short periods: had it worked as well on the ground as it did in the computer, it would have required 60 people for 4 days. Walking transport is more likely to require 8 or 10 people for 20 days—an appreciably lower investment of human energy, and distributed very differently. The graph shows sharp fluctuations in rolling manpower as the road gradient changes; walking manpower takes smaller steps going uphill, with the same number of workers and the same power input. The rocking foot allows both rocking and walking energy inputs to be adjusted automatically to match the terrain and available crew.

The walking mode is rhythmical. On a good road, one could get into the swing of things for minutes on end, rather like rowing a galley: Heyerdahl somewhere mentions that this is possible even in Mode VII, with ropes. Rolling/sliding seems more like a stop-and-go operation, with frequent pauses while the track is carried forward and adjusted. With models, the walking rig halved the number of oscillations required to move an object its own diameter. This suggests that on level ground, walking speed might rise above 150 m/hr.

A Ceremonial Function for Walking?

Considering the probable functions and manner of use of *moai* (MacIntyre, in press) it might well be that it was necessary for a *moai* to be seen to walk to his *ahu* with the dignity befitting a chieftain. (Van Tilburg insightfully proposed a supine position — in contrast to prone — for much the same reason.) In the absence of knowledgeable native informants, I see no way to investigate this except possibly by comparison with the Middle East, where writing overlapped the use of similar oracular statues, but I know of no relevant texts. The central question is, "At what moment, between separation from the living rock and erection at the *ahu*, does a *moai* become inhabited?" (The argument is cognate to the ongoing debate in our own culture about the moment at which a fetus is "ensouled". Scripture clearly implies that this happens with the first breath (Gen. 2:7), symmetrical with the universally accepted departure at the last breath, but argument nevertheless rages. Our own debate may be nonscientific and medieval, but—since US citizens are willing to kill each other over the question today—it cannot be ignored.) I suggest that this question was a matter of concern to Rapanui society before its collapse, and that they too may have had more than one answer.

The officiating priest will surely have insisted that only after ceremonial installation of the *moai* eyes does it become aware. On the other hand, those who knew him in life and have worked with him for months in the quarry and along the road will surely have personalized him much earlier. They are unlikely to have regarded transport as "moving a large rock", and their attitude would have been more in the vein of "Helping Chief So-and-so to his new home". Grammatical voice may be significant here: "the statues walked" rather than "we walked the statues". If this is a real difference, and not an artifact of translation, it might point to the feeling described above, of helping rather than doing The trip will have had aspects of holiday about it, with the incidents and accidents of travel being interpreted in the light of remembered idiosyncrasies of the person represented by the *moai*—"He always was a clumsy old chap", and "Let's take a break while he looks over his garden". If *moai* were oracular (MacIntyre, in press), there is every reason to believe that they scolded their handlers for mistreatment during transport, and that something approaching normal dialog transpired between *moai* and handlers.

In any case, it is probably not wise to assume the validity of a strictly engineering approach to *moai* transport. If *moai* cannot be carved without proper ritual (Heyerdahl 1989:202), it is almost certain that similar ritual surrounds transport. Heyerdahl (1989:227) reports that his informant Leonardo had both a song for walking the *moai* and a special word, *neke-neke* to describe the *moai's* walk replacing the usual *haere*. Fuentes (1960) glosses *neke-neke* as "to inch forward by moving the body, due to disabled legs or the lack thereof", a motion which Leonardo indicated by pivoting alternately about the balls of his feet and his heels, rocking slightly but keeping his legs still and knees stiff. Perhaps not surprisingly for a process involving ropes, Leonardo built a string figure for the walking ceremony (Heyerdahl 1989:225). These are known the world over (Jayne 1906), often as children's games, but originally a form of magic, perhaps for trapping evil spirits. However, if Leonardo's is among the 102 Rapanui figures known to the International String Figure Association, it is not identified by function (personal communication Mark Sherman).

One concludes that either Heyerdahl's informants were consummate con artists capable of delivering appropriate tidbits on demand to please Heyerdahl—as Samoan informants once did for Margaret Mead, according to Freeman (1983)—or they knew something about how *moai* had been traditionally made and moved. Against this possibility, one should realize that sexual titillation is much easier to invent, and more fun to spread, than workable engineering hypotheses.

Field Marks

A hypothesis which cannot be falsified is not very helpful, but in the absence of a time machine, I don't see how to falsify this one. Still, there are field marks which would support the idea of walking moai: (1) Most convincing would be a Sam-sized *moai* at the quarry with a rocking base, but this would not exist if the rocker had been a wooden cradle; (2) Abrasion tracks. These would weather quickly (Charola 1997, Domaslowski and Bahamondez 1997), but if preserved—under soil, perhaps—should look something like Figure 9. Even a wooden rocker might leave a few marks, depending upon how many small rocks were embedded in it.

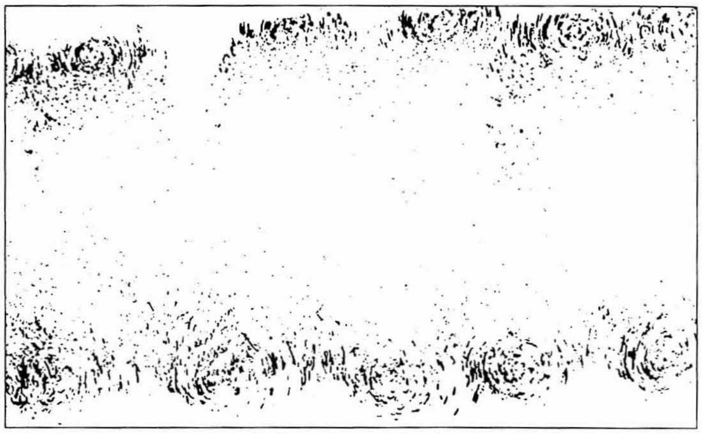

Figure 9. Probable appearance of the tracks of a walking *moai* (made by the model of Figure 8 with coarse sandpaper on the bottom of the rocking foot, walked over scratch board).

While this discussion suggests that walking is a viable mode of transport for the average *moai*, it does not follow that all *moai* walked. If I had to move Paro, I might try a Mulloy "centipede".

Finally, the limiting resource whose lack would immobilize *moai* most plausibly appears to be neither manpower nor timber, but rope, as Bahn and Flenley also suggest (1992:143). All methods considered require strong rope. Rope making requires a lot of bark, and *Triumfetta* (*hau*) might well have been the 2nd Rapa Nui plant to be driven to "commercial extinction" after the native palm. Perhaps the *moai* at Rano Raraku were waiting for more *Triumfetta* to grow. The timber rig takes less rope than any other method, but even so, the inconspicuous lashings of the model consumed several score "scale meters". How many meters of *Triumfetta* branches go into a meter of rope?

Conclusion

The transport model presented here—like all the others—is idiosyncratic and describes only how the author would attempt to move a *moai*. It meets the ordinary *sine qua non* tests (Van Tilburg 1996) of logic, effectiveness, and the limitations of Rapanui technology and resources. Yet it is not falsifiable and only weakly verifiable, for the one testable hypothesis offered is the characteristic field mark, and there is only a small chance that such marks would have survived several centuries of weathering (but absence of evidence is not evidence of absence). On the other hand, it offers a simple and highly efficient method by which *moai* might have walked to their *ahu*, in keeping with traditional Rapanui information. Perhaps its most important contribution is to suggest some caution about drawing deep sociological conclusions from unverifiable hypotheses about *moai* transport. Heizer (1966) remarked that in contemporary South East Asia and Madagascar (from the same stock which peopled the Pacific) the transport of statues weighing less than 15 tons did not require social organization beyond the extended family.

As Van Tilburg has demonstrated, it is less annoying and more educational to falsify one's own hypotheses than to have others do it for you. If UCLA's 9 ton cement *moai* becomes available for additional experiments, it might be fun to see how it maneuvers in a walking rig.

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Footnotes

[1] Personal communication during a public discussion with an anonymous Australian historian at an International Geophysical Union meeting in Melbourne c. 1973.

[2] I noticed this after Surtsey erupted in 1963, from the same photograph which Mott Greene has on the cover of his book, but he wrote about it first (1992), and he did a historian's job of it.

[3] I apologize for not having realized how interesting this tidbit would become in later years, and for not making a bibliographic note of the book. All I can say is that it had been printed in India, on paper that did not lie flat in its binding, and it was near the shelf I was looking for. I believe the cover was dark red.

[4] Straight poles, which we seem to assume are available for constructing devices for moving *moai*, are not abundant in the temperate savannah or deciduous forest which most probably resembles Rapa Nui's original forestation. They occur when trees grow vertically for light, as in closely spaced coniferous forests, and in tropical rainforests —neither of which Rapa Nui possessed.